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RELATION OF WIND TO TOPOGRAPHY OF COASTAL DRIFT SANDS

PEHR OLSSON-SEFFER
Mexico City

The work on which this paper is based covers a number of years and a variety of marine sea-coasts. Sand formations have been studied by the writer on different coasts in Europe, on sea-shores in Australia, South Sea Islands, North and Central America. In a recent paper¹ the origin and development of such sand formations have been discussed and it is the intention to present here some observations on the wind in its relation to the topographical features of these sands.

As a geological agent the wind exercises a considerable modifying power, although its character is very unsteady. It manifests its influence by carrying fine particles of soil, depositing these, denuding rocks that stand in its way, and indirectly affecting the topography of the earth's surface by distributing moisture and limiting vegetation.

The moving sands of sea-shores afford ample opportunity for study of the methods of the wind in its work of denudation. It can often be seen how the sand carried over the surface of rocks sometimes wears them quite smooth, or covers them with scratches and furrow marks. This abrasion by the wind-transported material is always noticeable in dune districts, at least on the wind-worn pebbles, but also on the remains of trees which have been partly buried by the drifting sand, and then the protruding parts have been slowly carved and worn by the sand (Fig. 2).

In its weathering action wind has a constant tendency to break down the stones, gravel, and coarser soil particles into fine dust, and it is assisted in this work by the moisture. If it was not for the looseness of the sand, which allows the rain to percolate rapidly and thus to carry the fine dust deep into the ground, the persistent combined action of wind and moisture would suffice to prepare the quantity of

¹ Pehr Olsson-Seffer, "Genesis and Development of Sand Formations on Marine Coasts," *Boletín de la Sociedad de Geografía y Estadística*, Mexico (in press).

fine material needed to supply plants with soluble substances, and thus to allow a cover of vegetation to gain a foothold.

The action of wind as a transporting agent when removing the denuded rock material, whether soluble or insoluble, as soon as it appears at the surface is one of the most important factors in the denudation processes. Walther¹ calls this phenomenon *deflation* and he considers it to be of even more consequence than abrasion. Through deflation fresh rock is consequently exposed to the eroding forces, and it is evident that this action must be considerable, especially on the coasts with their moist climate.

The softer strata of rocks are worn more deeply by deflation, co-

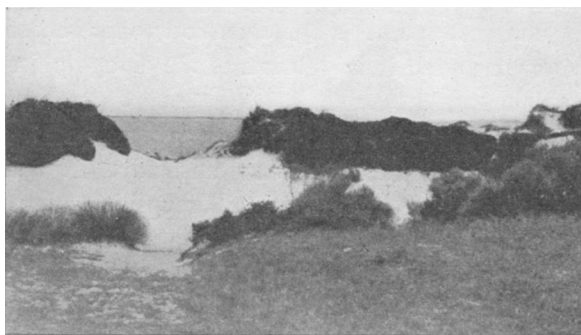


FIG. 1.—Established and rejuvenated dune surface at Fremantle, Western Australia.

operating with abrasion, and the harder layers are left to form cornices. On account of the abrasion being greater near the surface where the wind current carries a greater load of sand, the lower parts of rocks are often eroded more rapidly than the upper. Evidence of this can be seen in the “balancing rocks” not infrequently occurring in the neighborhood of extensive sand formations. The writer has seen such rocks on many coastal sands, near Port Fairy in Victoria, for instance, on the West Australian coast, at Port Said in Egypt, and at Carmel Bay in California.

It is especially the fine particles of sand which are liable to be transported by the wind; but as the fine sand retains its moisture better

¹ *Das Gesetz der Wüstenbildung*, 1900.

than that of coarser texture, because of its greater capillarity, it is evident that, if some means are furnished which increase the amount of moisture, or rather lessen the evaporation, the action of wind will be in a measure counterbalanced. This is accomplished by a vegetative covering, which fixes the sand and thus protects it against the influence of the air currents. The climatic conditions, especially a larger or smaller degree of moisture, is therefore a great factor in the development of eolian sand formations.

It is a matter of everyday observation that the velocity of the wind changes rapidly and varies considerably. A wind which appears to be very uniform is, when subjected to close observation, only a series of gusts following each other with intervals of lesser velocity, and even of complete calm. The carrying capacity of the wind is, therefore, also very variable. The wind that one moment carries and drops pebbles, a few minutes later carries only sand for deposition, and finer sand follows coarser.

A series of observations made by the writer in this connection will here be referred to.

Methods of observation.—The experiments were conducted on the sandy beach north of Fremantle in Western Australia during September and October, 1902, and they were intended to ascertain the carrying capacity of wind of certain velocities, as well as the effect of these winds on the movements of the sand.

For measuring the velocity of wind I used anemometers of Crova type, purchased from Negretti and Zambra in London. The instrument was placed on a support steadily secured in the sand, and elevated 5 cm. above the ground. It was not practicable to lower the apparatus more, because nearer the surface the amount of sand particles carried by the air current was still greater than at the elevation chosen, and I found that the results were somewhat influenced by the density of the sand-shower.

Samples of sand of different grain sizes were secured by sifting through sieves with meshes of known diameter. Three sizes were used, 0.2 mm. (fine sand), 0.3 (medium sand), and 0.6 (coarse sand).

Of each kind of sand a quantity of about 5 cu. dm. was dyed with different colors, black, bright blue, and orange being considered the most suitable and best distinguishable from the natural sand. The

sand was dyed in colored water and then thoroughly dried. By weighing the colored sand I satisfied myself that the weight had not materially increased through this process. At the time the observations were made, this colored sand was laid out in ridges transverse or parallel to the direction of the wind or in small heaps, the different results being noted in each case.

In order to ascertain the height to which different grades of sand were lifted by the wind I devised a simple contrivance, which seemed

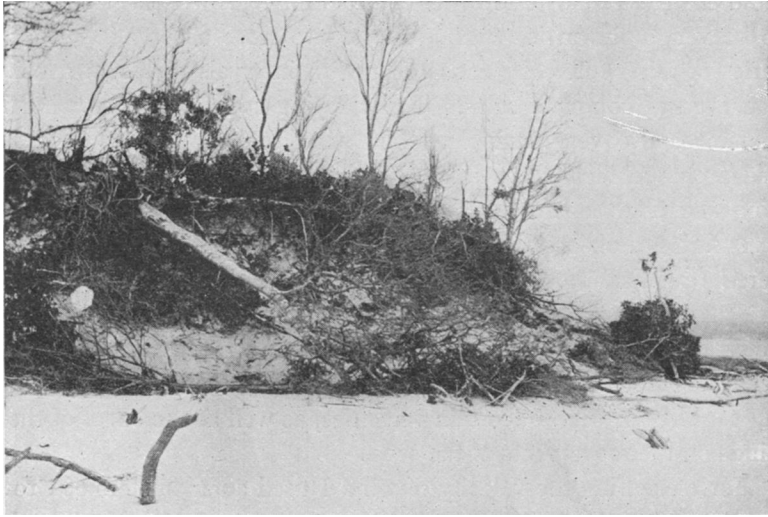


FIG. 2.—Established dune destroyed by the wind. Near Southport, Queensland.

to fill the purpose. Five sheets of corrugated iron held together by a frame, were placed above each other at a distance of 2 cm. with the lowest floor resting on the ground, and with the wrinkles at right angles to the direction in which the sand moved. The front of each sheet was flattened for about 12 cm., so as not to give any obstruction to the wind or sand. These sharp, parallel edges divided the sand-shower, and the grains were collected in the folds of the apparatus. By closing the front and sweeping the different “floors” samples for examination were secured. For the sake of brevity I have in the following pages spoken of this apparatus as the “sand separator.”

As my object was principally to find out the influence of wind in the layers near the surface or those which carry the greatest quantity of sand and come into contact with the lowest strata of the vegetation, I did not have the sand separator arranged to receive sand which was lifted higher than 8 cm. above the surface.

It seemed, further, to be of considerable interest to know how great the difference of the velocity of wind was on level and broken ground, and consequently to what extent a rough surface influenced the movement of sand. On a vacant lot, south of Fremantle, where the sand had been covered with a layer of loam for agricultural purposes, I had opportunity to make some observations in that direction, and subsequently I measured the surface velocity of air on a grassy plot adjoining a field of drifting sand.

Day after day the experiments were continued under different conditions of wind and humidity, and with the aid of an assistant I was able to make careful observations of the tactics of the moving sand, and to secure some results which are not without interest.

Velocity of wind.—Of the hourly registrations made, those for six days will be given as samples. The place of observation was on an open beach, 40 m. from shore. Angle of sloping about 12° . The following table indicates the result. Velocity in meters per second.

	I	II	III	IV	V	VI
7 A.M.	0.6	11.3	10.9	8.6	3.1	10.4
8 	1.3	12.5	12.3	12.7	3.9	10.9
9 	1.9	13.1	14.2	14.1	4.7	11.5
10 	2.4	13.8	15.7	14.9	5.6	14.2
11 	2.1	14.6	18.2	23.7	7.1	15.7
12 	4.5	15.9	19.5	22.5	7.6	18.6
1 P.M.	4.9	17.6	16.3	23.2	7.9	18.9
2 	6.0	19.4	14.9	14.1	8.7	17.2
3 	12.8	22.4	15.1	22.6	12.3	18.4
4 	13.9	21.2	15.6	22.3	14.1	20.2
5 	13.7	19.6	13.2	14.7	11.6	19.7
6 	13.3	18.3	12.9	20.4	8.7	16.1

Result of experiments on carrying capacity.—A few of the observations made will here be given to show the details obtained. The Roman numerals refer to corresponding days in the table of velocities.

I. No drifting was observed in the forenoon. Slight movement was noticed between 1 and 2 o'clock. During the next hour the sand

separator had received a quantity of grains on each floor. Mechanical analysis of these grains showed that on the lowest floor A, on a level with the surrounding ground where the greatest quantity of sand had collected, many different grades were represented. This is self-evident as the grains here had only rolled and not been lifted by the wind; at least not higher than 2 cm., in which case they were intercepted by the next higher floor B. The wind was gusty, but the force of the separate gusts was comparatively uniform, and the intervals of wind of lesser velocity, brief and somewhat regular in length.

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.—	0.02–0.05	trace
	0.05–0.1	2.2
	0.1–0.2	13.1
	0.2–0.3	56.2
	0.3–0.5	21.5
	0.5–1	5.6
	1–2	1.4
Floor B.—	0.02–0.05	0.8
	0.05–0.1	5.2
	0.1–0.2	42.9
	0.2–0.3	44.5
	0.3–0.5	6.6
Floor C.—	0.02–0.05	12.3
	0.05–0.1	16.6
	0.1–0.2	58.4
	0.2–0.3	10.7
	0.3–0.5	2.0
Floor D.—	0.02–0.05	37.4
	0.05–0.1	56.7
	0.1–0.2	5.9
Floor E.—	0.02–0.05	72.5
	0.05–0.1	26.3
	0.1–0.2	1.2

The coarsest material with certainty lifted by a wind of a velocity of 12.8 m. per second was, as indicated by the above table, medium sand, and the greatest height to which this sand was lifted, 4–6 cm.

During the same period of time the colored sand samples exposed to the wind were distributed as follows:

Fine sand	12 m.
Medium sand	12
Coarse sand	7.5

II. During morning hours the drifting was insignificant as the surface of the ground was still somewhat moist with the abundant

dew fall. But at 9 o'clock, although the force of wind had not increased much, the sand was moving briskly and the shifting continued through the day.

The sand separator was kept at the same distance from shore as on day I, but the ground was so slightly sloping as to be almost horizontal. The day was warm and the sand quite dry. From 2 to 3 o'clock the separator was in action, and subsequent analysis gave the following result:

PERCENTAGE OF DIFFERENT GRADES

	Diameter in mm.	Per Cent.
Floor A.	—0.02-0.5	trace
	0.05-0.1	6.4
	0.1-0.2	10.2
	0.2-0.3	41.3
	0.3-0.5	28.4
	0.5-1	9.6
	1-2	3.5
Floor B.	2-4	0.6
	—0.02-0.05	1.7
	0.05-0.1	3.3
	0.1-0.2	26.5
	0.2-0.3	47.8
	0.3-0.5	14.1
	0.5-1	6.6
Floor C.	—0.02-0.05	5.1
	0.05-0.1	10.0
	0.1-0.2	23.4
	0.2-0.3	41.2
	0.3-0.5	6.7
	0.5-1	3.6
Floor D.	—0.02-0.05	16.3
	0.05-0.1	34.7
	0.1-0.2	28.5
	0.2-0.3	12.1
	0.3-0.5	8.4
Floor E.	—0.02-0.05	32.5
	0.05-0.1	34.1
	0.1-0.2	16.8
	0.2-0.3	5.4
	0.3-0.5	1.2

A wind with a velocity of 22.4 m. per second was thus able to lift medium sand at least 8 cm. and coarse sand 4-6 cm. The coarsest grains at all raised above the surface had a diameter of 1 mm.

As for the distance to which the wind was able to transport colored grains I found grains 4.3 m. away from the original place of exposure after 15 minutes, while grains of 0.2 mm. diameter were carried at

least as far as 12 m. where they were intercepted by a white canvas sheet. These distances are only relative values of the carrying capacity, as they show only what has been observed with the crude methods employed; a number of grains are, no doubt, carried much farther but cannot be distinguished on the sandy ground.

IV. From about 8:15 A. M. the sand was drifting slowly, increasing by degrees with the increase of force of wind and the rise of temperature and consequent desiccation of the sand. Shortly after noon a damp fog came driving inland from the ocean, and a decrease in the movement of the sand was at once evident. A small shower of rain followed and drifting ceased completely. Evaporation was not sufficient to dry the sand during the rest of the day, and in spite of the comparatively high wind no more drifting was observed.

VI. Between 10 and 11 o'clock in the forenoon the separator was at work, and collected samples of sand, the mechanical analysis of which is given below. The sand was completely dry to a depth of about 5 cm. and the separator was placed on ground sloping in an angle of 25 degrees.

PERCENTAGE OF DIFFERENT GRADES		
	Diameter in mm.	Per Cent.
Floor A.	—0.02—0.05	trace
	0.05—0.1	1.6
	0.1—0.2	10.5
	0.2—0.3	60.1
	0.3—0.5	17.8
	0.5—1	6.7
	1. —2.	3.3
Floor B.	—0.02—0.05	trace
	0.05—0.1	3.8
	0.1—0.2	37.3
	0.2—0.3	51.9
	0.3—0.5	7.0
Floor C.	—0.02—0.05	5.7
	0.05—0.1	12.4
	0.1—0.2	61.3
	0.2—0.3	14.5
	0.3—0.5	6.1
Floor D.	—0.02—0.05	21.3
	0.05—0.1	63.9
	0.1—0.2	12.6
	0.2—0.3	3.2
Floor E.	—0.02—0.05	64.8
	0.05—0.1	28.6
	0.1—0.2	5.1
	0.2—0.3	1.5

A wind with a velocity of 15.7 m. per second was thus able to lift grains of 9.3 mm. diameter to a height of 6-8 cm., and experiments for ascertaining the distance to which such grains were carried by the same wind showed this to be 8.6 m. in 30 minutes.

The few examples given are typical of a larger number (24) of mechanical analyses of series of samples collected with the sand separator during wind of different strength, but it is hardly necessary to furnish additional data, as a discussion of the facts given will bring out the points wanted for our present purpose.

For the solution of the problem of the carrying capacity of the wind, it is of primary importance to know whether the velocity is changing on or near the surface. Among the observations on velocity of wind in different heights, which have been recorded, we may mention those by Stevenson, Montaigny, Ragona, and Sokoloff. All these experiments show that *the velocity increases considerably with the height.*

A very significant feature of the above tables is that the bulk of sand on the two lowest floors is of such uniform size. I take this to indicate that the velocity of the lowest layers of air must be comparatively uniform, while the higher currents are of a more gusty character and are able to pick up the smaller grades of grains and lift them higher. It is an accepted fact that a current, which carries a load, is retarded, and the retardation is greater the larger the particles moved. Nearest to the ground there is a layer which on account of the friction against the uneven surface is comparatively inert, and we know that the velocity of the current in this layer increases only at a very slow rate with an increase in the speed of the layers next above it.¹ These circumstances put together tend to support the above theory that the movement of the lowest layer of the atmosphere is more uniform than the higher.

Although the bulk of sand on the lowest floor of the separator is greater than on any of the higher, the difference between the quantity of sand on A and B is not very remarkable. I understand this to prove that the larger part of sand moved by the wind is lifted from the ground, if only for a short distance. It seems at first sight as if all the material on the lowest floor or on the same level as the ground,

¹ J. A. Udden, *The Mechanical Composition of Wind Deposits*, 1898, p. 24.

had been pushed forward or rolled on the surface. But the opening between the floors is high enough to allow a considerable part of the grains to be lifted above ground. It seems most likely to me that the sand is moving in short jumps.

Different opinions have been expressed on this question. Brémontier considered that the sand is not lifted to any considerable height as he says:

Chacun des grains de sable dont elles (les dunes) sont composées n'est pas assez gros pour résister aux vents d'une certaine force; ni assez petit pour être enlevé comme de la poussière, ils ne font que rouler sur la surface dont ils sont arrachés, s'élèvent rarement à plus de 3 à 4 pouces d'hauteur.¹

Andersen² also maintains that the grains are mostly rolled on the surface. Berendt, Hagen, and Sokoloff, among others, admit that it is lifted quite high; the latter³ correctly assumes that the many different theories on this question most likely depend on the fact that the observations refer to different places on the dunes sometimes to the front slope, in other cases to the summit or to the leeward side.

Udden⁴ discusses this question in following words:

Materials finer than dune sand are wholly lifted up into swifter currents which promptly move them. The dune sand itself, on the other hand, is partly lifted and also partly rolled just as the grains of the nearest larger sizes. Working in this last manner the transporting power of the wind varies more nearly in approximation to its erosive force than to its lifting force. With changes in velocities the latter varies as the sixth power while the erosive force varies as the square. It is therefore much easier for the coarser ingredients to be rolled along with the dune sand than it is for the dune sand to be picked up and carried away with the finer ingredients.

This holds true and the cause of the greater resistance of the finer material is simply the greater coherence of the finer soil particles. In drawing any inferences with regard to these matters we must not forget, however, the influence which is exerted by the slope. On a horizontal surface the effect of wind is not so great as on a slope.

¹ "Mémoire sur les dunes," *Ann. des ponts et chaussées* (1), 1883, p. 148.

² *Om Klüffformationen*, 1861, p. 57.

³ Sokoloff, *Die Dünen*, 1894, p. 79.

⁴ *The Mechanical Composition of Wind Deposits*, 1888, pp. 24 ff.

This has been shown by Sokoloff¹ and two of the experiments already described, those on days I and II, illustrate the same fact. Although in the latter case the wind was swifter with nearly 10 meters per second the quantity of material moved as well as the percentage of the coarser grades was only very little larger than in the former case, when the separator was placed on a sloping surface.

Any obstruction that comes in the path of the wind will greatly reduce its force and consequently lessen the movements of the sand. It is on this principle that some of the methods of arresting drift sand are based. Planting rows of grasses or trees, or the making of fences of sticks and other material on the dunes are means employed for this purpose. Scanty rows of grasses act more effectively as windbreaks than as regular binders of the soil, and in planting such "sandstays" it is important to get the right distance between the rows, which varies at different localities with the exposure to wind and coarseness of the sand. If the local conditions have not been studied and if the disposal of the windbreaks has not been done properly, the results will be unsatisfactory. Too long distance between the rows will not prevent drifting, and too close planting is unnecessarily expensive.

The experiments conducted for the purpose of ascertaining difference in velocity of wind on an even and a rough surface gave the results shown below:

NUMBER OF SERIES	NUMBER OF OBSERVATIONS	MEAN VELOCITY PER SECOND IN METER		
		On Even Surface	On Rough Surface	On Grass Covered Surface
I.....	7	8.4	5.2	4.3
II.....	11	10.2	6.8	5.8
III.....	5	4.6	3.1	2.6
IV.....	6	9.8	6.3	5.1
V.....	3	16.2	10.6	8.7
VI.....	6	5.4	3.7	3.0

The following compilation of these results will show the actual difference of velocities as well as the proportion expressed in per cent. of velocity on the even surface.

¹ *Die Dünen*, 1894, p. 289.

DIFFERENCE OF WIND VELOCITIES PER SECOND IN METER

NUMBER OF SERIES	BETWEEN EVEN AND ROUGH SURFACE		BETWEEN EVEN AND GRASSY SURFACE		BETWEEN ROUGH AND GRASSY SURFACE	
	Actual Difference	Per Cent.	Actual Difference	Per Cent.	Actual Difference	Per Cent.
I.....	3.2	61.9	4.1	51.1	0.9	82.6
II.....	3.4	66.6	4.4	56.8	1.0	85.2
III.....	1.5	67.5	2.0	56.3	0.5	83.8
IV.....	3.5	64.2	4.7	52.0	1.2	80.9
V.....	5.6	65.4	7.5	53.7	1.9	82.0
VI.....	1.7	68.5	2.4	55.5	0.7	81.0

In these experiments the anemometers were placed on a board on the ground, thus raised 3 cm. above the surface. The centrum of the instrument was on a level with the top of the low grass turf in the case of the grassy surface.

We find from these accumulated facts that the mean velocity on the even surface surpassed that on the rough ground by 3.15 m. per second or 34.7 per cent. F. H. King¹ gives the velocity over smooth ground as more than 40 per cent. greater than that on a rough surface. The difference in my results may have been caused by different conditions under which the experiments were conducted. King does not give any information about the method by which his results were obtained so that actual comparison is impossible. I consider the difference as being of minor importance, as by both these series of experiments it is clearly shown that the velocity of wind over a smooth surface is *at least* 34.7 per cent. greater than on uneven ground. Again, the velocity on grassy ground is still less than on bare rough surface. This is a fact of some practical importance in connection with planting on sandy soils, and it has a bearing of considerable weight on the vegetation on sand formations.

Through the investigation of Kihlman,² Warming,³ Hansen,⁴

¹ *Destructive Effects of Winds on Sandy Soils and Light Sandy Loams with Methods of Prevention*, Eleventh Annual Report of Agricultural Experiment Station of Wisconsin University, 1895, p. 332.

² Pflanzenbiologische Studien aus Russisch Lappland," *Acta Soc. F. Fl. F.*, VI, 1890.

³ *Plantensamfund*, 1895; "Der Wind als pflanzengeographischer Faktor," *Engl. bot. Jahrb.*, Vol. XXXI, 1902.

⁴ *Die Vegetation der ostfriesischen Inseln*, 1901.

and others, it is now a well-established fact that the movements of the atmosphere are of the greatest importance for the plants, especially because of the influence of winds on the transpiration processes. With regard to vegetation on coastal sands wind is a factor of particular moment. The difference in wind velocities on open soil, on a surface more or less uneven, or covered with a more or less dense vegetation, is therefore of great significance, and we shall be able to show some effects of this eolian influence in the following pages.

The direction of wind on different shores is further a factor which must not be overlooked as it plays an important rôle, not only in the development and topography of the sand formations, but also in the distribution of plants on the coast.

As a general rule we can lay down the law that on every coast where sand dunes occur the offshore wind is prevailing. There are, however, a great many exceptions to this rule, where the local topography or other factors have been the cause of dune development.

On some coasts, as that of Jutland, where the supply of marine sand seems to be inexhaustible, the prevailing westerly winds from the sea drive the sand inland from the beach, continuously adding to the volume of sand. On other coasts, as that of Gascony, strong land winds occur, which often return considerable quantities of sand to the sea.

On the Pacific coast of America near San Francisco, and near Salina Cruz in Mexico I noticed that the sand cast upon the beach by the northerly and westerly winds was again driven back into the sea by the winds from the south and east. Similar conditions exist on many other coasts where the topography is favorable to such a forward and backward movement.

The force of the wind is augmented or diminished according to the season, but the result as regards sand formations depends greatly upon the direction of the coast. On the windward side of many islands high dunes are formed, as for instance on the northern coast of Oahu in the Hawaii group where they reach about 30 feet.

Typical coastal sand formations.—Very little variation is noticed in the formation of sand drifts on marine coasts. Wherever the drifting sand encounters an obstacle in its way such as a shrub or a piece of wood, or a rock, there it deposits on the leeward side. Gener-

ally we meet, however, with a level beach of a varying width, and then the coastal dune rises slowly at an angle varying from $4-16^{\circ}$ on the wind side. Its height varies on different coasts according to the supply of material and the prevailing direction of the wind.

On very long, straight, and open coasts the wind strikes the sand over a long distance with the same force and under almost identical conditions. On such coasts we find long stretches of dunes showing a little diversified topography. As a rule the dunes are very little curved and run at right angles to the direction of the wind.

The diurnal variation of direction and force of winds which always is considerable on marine coasts exercises some influence upon the development of the drift-sand formations. The angle of deflection from the direction of the annual wind resultant differs in summer and winter, and from observations of these meteorological data in a locality with drift sands it is possible to calculate to some extent as to the annual movement and changes of the sand formations.

Usually the downward eddy behind the coastal dune sweeps over the stretch of land immediately following, and regular dunes are not formed before some distance from the coastal dune. These first dunes are formed round some obstacle, and their form is usually oval, pointing toward the wind and the coast, but sometimes crescentic, and convex to the wind. These small advance dunes are followed by trains of large dunes, nearly uniform in shape. The wind sweeps with brisk velocity upward along the gentle gradient and carries the sand to the brink where it is deposited on the steep lee-side which is further increased by the undercutting of the eddy.

Beyond the reach and influence of the strong sea breeze the dunes are more irregular, and lateral inequalities are formed connecting the various individual dunes into long ridges. These travel forward in a continuous march, slowly but surely. The form and location of the drift changes gradually.

A dune region shows a more or less undulating surface, which suddenly may be broken up into quite high hills or ridges. Sometimes, when the forward march of the dunes has been stopped the dune belt is continued inland in a gently undulating sand field.

In a dune region many different stages of dune development are observed, from the embryonic living dune to the large established

mountain-like sand dune covered with vegetation. Very often such finished dunes are again broken up by the wind (Fig. 1). On these rejuvenated dunes the usual series of development takes place from the very beginning, and they have often a peculiar character, resulting from the remaining remnants of the old vegetation covering and the new plant immigrants which have arrived after the complete or partial destruction of the dune.

It is a rule that the inner dunes in a complex are higher than those nearer the beach because the horizontal directions of wind are deflected.¹

Dunes do not travel extensively. Those in Brittany are said to move 27 feet a year for 200 years. On the coast of Norfolk facing the North Sea the dunes travel 150-80 feet a year, according to Lapparent. I have not been able to find conclusive evidence regarding a more rapid advance of dunes than 42 feet in one year, which is the rate of advance of some dunes near Vera Cruz in Mexico.

Dr. Baschin² reports a mean drift of moving sand ridges on the west coast of Fanö, the northernmost of the islands of North Friesland, of about 10 feet a day. The author's explanation is that on a large dune more material must be driven to the lee-side before any displacement of the crest becomes evident, while the small sand ridges on which his experiments were made moved more rapidly. He also maintains that the slope on the leeward side is due simply to the fall of the sand as the crest of the dune moves forward. I hold with Bertoldy that the steep slope is due not only to the fall of the sand but also to the effect of the vortex of air round a horizontal axis formed on the lee-side of the dune.

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¹Franz Czerny, "Die Wirkungen der Winde auf die Gestaltung der Erde," *Peterm. Geog. Mitt.*, 1876, Ergänzh. 48, p. 27.

²*Zeitschrift der Ges. für Erdkunde zu Berlin*, No. 6, 1903.

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